Modelling and Analysis of Centralized Spring

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***Abstract*— Centralized spring (Rotor Bearing Damper Bracket) is a component which forms a part of rotor bearing assembly, where its criticality can be gauged from the fact that the component supports and locates on one of the main shafts which transfer the power from the compressor to turbine. The design was finalized with subjected to various assembly constraints, life consideration and manufacturing feasibilities. RBDB absorbs dynamic radial loads and axial thrust of the shaft spool. Hence, the component has to perform extremely important function with assembly constraints, rotor dynamic requirement and weight limitations which necessitate a detailed stress analysis. The objective of this paper is to conduct breakout research to explore the distribution of stress in centralized spring. The 3D model was done by using CAD package and the model was used to produce rapid prototype model by stereolithography process because of its ability to provide the models that are photosensitive in nature. Finite element analysis has been carried out on centralized spring and as well as experimental analysis on the prototype (photoelastic analysis) is also conducted. The comparison of the experimental with the numerical results is the end result of the paper. Generation of full field stress contours corresponding to aero engine component is the outcome of the study.**

Keywords*— CENTRALIZED SPRING, FINITE ELEMENT ANALYSIS, RAPID PROTOTYPING, STEREO LITHOGRAPHY, PHOTO ELASTICITY.

INTRODUCTION

Stress analysis plays a vital role in a structural component which predicts the stress induced to the loading condition and its behaivor with respect to the loading condition. The Gas Turbine is an internal combustion rotary engine, the most widely known example of which is the jet aircraft engine. The CENTRALISING SPRING is a component that was chosen for the purpose of study as shown in the figure 1. It is also known as ROTOR BEARING DAMPER BRACKET. The original design was finalized by RSIF module subject to various assembly constraints, life consideration and manufacturing feasibilities (1).

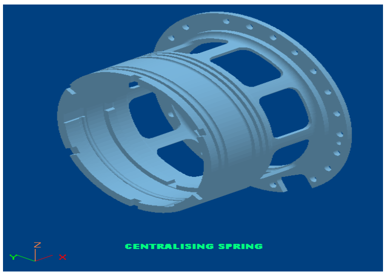

Fig 1: Centralizing spring

The Centralizing springs forms a part of the ROTOR BEARING assembly. Its criticality can be gauged from fact that the component supports and located one of the main shafts that transfers the power from the compressor to the turbine. It absorbs dynamic radial loads and axial thrust of the shaft spool.

Photoelasticity was developed to apply optical principles to solve engineering problems of elasticity. The method relies on the birefreingence property exhibited by transpatrent plastics. In particular, the phenomenon pf stress (or load) induced birefingence is uitilized where the material becomes birefrinence under the influence of external loading. The Finite Element Method (FEM) is a numerical technique to obtain approximate solutions to a wide variety of engineering problems where the variables are related by means of algebraic, differential and integral equations. Mathematically, the structure to be analyzed is subdivided into a mesh of finite sized elements of simple shape. Within each element, the variation of displacement is determined by simple polynomial shape functions and nodal displacements. Equations for the strains and stresses are developed in terms of the unknown nodal displacements. From this, the equations of equilibrium are assembled in a matrix form which can be easily be programmed and solved on a computer. After applying the appropriate boundary conditions, the nodal displacements are found by solving the matrix stiffness equation. Once the nodal displacements are known, element stresses and strains can be calculated. Within each of these modeling schemes, we can insert numerous algorithms (functions), which may make the system behave linearly or non-linearly. Linear systems are far less complex and generally ignore many subtleties of model loading & behavior. Non-linear systems can account for more realistic behavior such as plastic deformation, changing loads etc. and is capable of testing a component all the way to failure (2). The main objective of this paper is to conduct breakout research to explore the distribution of stress in centralized spring. The 3D model was done by using CAD package and the model was used to produce rapid prototype model by stereolithography process because of its ability to provide the models that are photosensitive in nature. Finite element analysis has been carried out on centralized spring and as well as experimental analysis on the prototype (photoelastic analysis) is also conducted. The comparison of the experimental with the numerical results is the end result of the paper. Generation of full field stress contours corresponding to aero engine component is the outcome of the study. An accurate assessment of the operating stress or strains is an essential step in the fatigue life evaluation but a more depending task is to mitigate fatigue damage on these parts. Numerical methods and computer programming may not always be suitable for the analysis of the coupling of multi stress concentration of features which require different experimental techniques like photo elasticity, holography, etc. Hence integrated method of using finite element technique and photo elasticity can provide accurate assessment of stress situation.

II Literature review

The literature contributing to the application of Rapid prototyping for photo elastic analysis is mentioned in Fusion of Digital photoelasticity, Rapid prototyping and Rapid tooling Technologies by K.Ramesh, S.G.Dhande [3]. It states that Stereolithography is the suitable process for producing photo elastic material because of its ability to provide the models that are photo elastically sensitive. In this research work the key issue is the identification of suitable resin to be used in making the model by Rapid Tooling, the SG95 resin meets the requirement of photo elastic analysis and it suitable for stress freezing and slicing process. Depending on the weave pattern used to construct the STL model. Calvert and Geoff (1994) Rapid prototyping for experimental analysis has discussed - The use of Rapid prototyping techniques to provide a quicker method of constructing models for experimental analysis; which will allow experimental data to become available prior to a design being committed to tooling and production [4]. Loebig, Thomas G., Anderson, Donald D. (1997) Rapid prototyping modeling for three dimensional photo elastic stress analysis has discussed – modern techniques in the areas of computing and manufacturing can be used to build accurate models of human bones which can include internal geometries features, an established method of three dimensional photo elastic stress analysis, stress freezing, can be applied using epoxy SLA models for experimental stress analysis [5]. Folkestad, James, E, Johnson, Russell.L (2002) Integrated rapid prototyping and rapid tooling (IRPRT) has discussed – the strategic integration of rapid prototyping and rapid tooling is being used for getting product to the market quickly by resolving a long standing conflict between design and manufacturing. Currently rapid tooling can be produced at such reduced cost and time that the tool is considered to be disposable. The ability to produce inexpensive tooling allows the life cycle to be fundamentally changed, incorporating the concept and tooling review into one development phase and allowing both design and manufacturing requirements to b identified. Thus this approach has allowed management top release product based on competitive market strategy rather than an estimated deadline [6].

III Stereolithography based building of centralizing spring for the photoelastic analysis

Among many RP techniques, Stereolithography (SLA) process gives better dimensional accuracy and surface finish with respect to part quality Characteristics [7]. Figure 2 presents an overview of SLA process in which intricate parts of a plastic monomer are directly built by photo polymerization process with the model constructed using a Computer Aided Design (CAD) package [8].
The process of SLA involves: Modelling of part with a CAD package to generate a 3D Solid model: Conversion of 3D solid model into Standardized Triangular Language (STL) file format to create volumetric mesh and creation of support structure: Slicing of STL format of 3Dsolid model to provide a series of cross sectional layers: exporting the sliced model to the computer of Stereolithography apparatus(SLA) : building the support structure and the part layer by layer over a vat of specially designed liquid resin with a Neodymium-doped yttrium vanadate (Nd:YV04) laser , which traces the outline of the planer sections and solidify the resin in SLA; removal of support structure to get the green part: post curing apparatus (PCA), which is either a controlled furnace or an ultraviolet oven.

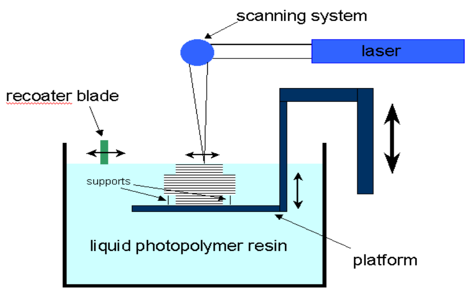

Figure 2 Schematic of SLA process

Model preparation is an integral part of the photo elastic investigation. 3-D model preparation is an expensive and time consuming process, particularly when complicated geometries are to be duplicated and also need to be optimized. The disadvantage of model making difficulty is partially compensated by the amount of accurate full field stress data provided by the stress-frozen model. Also during the stress freezing phase the loading can be simulated as close as possible to the actual condition by photo elastic analyst. If the model-making phase of photo elastic testing can be completed quickly, then the capability of photoelasticity is greatly enhanced, especially in the cases of design iteration studies [4]. On the consideration of above, the objective of the paper is to emphasize of Rapid prototyping for the generation of photoelastic models for the stress analysis.

Stereolithography (SLA), the first RP system for mechanical parts, was pioneered, designed developed and commercialized in 1988 by 3D systems of Valencia, CA, USA. The denotation of the word Stereolithography can be known by examining the constituent word “STEREO” and “LITHOGRAPHY”. STEREO means “having or dealing with 3D space” and LITHOGRAPHY means “the process of printing on a surface”. Thus stereolithography is a 3D process that produces a solid model using proprietary software. In addition, LM processes require very little human intervention and setup time [9]. The part has been manufactured by taking the optimal values of major process parameters such as Layer thickness (0.125 microns), orientation (90^0) and Hatch Spacing (0.015mm) which enhances the mechanical strength of epoxy resin material in the SLA 5000 machine with SL5530 epoxy resin as shown in the figure 3 and the photoelastic model in figure 4.

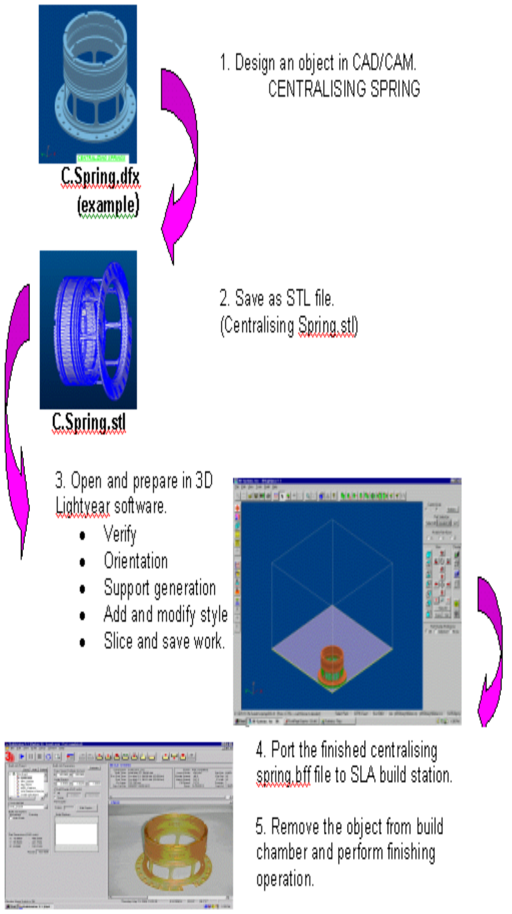

Figure 3 Stereolithography process overview [10].

Figure 4 Photo elastic models produced by SLA RP

IV PHOTOELASTIC ANALYSIS OF CENTRALISING SPRING

Photoelasticity is an experimental technique for stress and strain analysis which is particularly useful for members having complicated geometry, loading conditions or both. A schematic of the photo elastic model is shown in the figure 3[11]. All the design features which affect the stress distribution of the component were accurately reproduced in the full-scale epoxy resin model where epoxy resin 5530 was used for the model preparation [1, 2]. This process of selection inherently involves the optimization of various design parameters of the component. The design parameters are length and diameters which contribute to the component stiffness get fixed due to assembly constraints. So the parameters available for modification and optimization are number of flex webs and the geometrical features of the flex webs i.e., Width of the Web, Thickness of the slot, Length of the slot, Edge fillet radius

A Stress freezing of the model

To ensure proper simulation of the actual loading conditions special fixtures were designed and developed. In the original engine the shaft load is transmitted through the bearing race onto the shaft. One end of the shaft model is firmly bolted to the flange and at the other end a predetermined bending load of 500grams is applied through a sleeve that fits snugly in the inner periphery of the model and standard stress freezing cycle for the material SL5530 was carried out in a temperature controlled oven. The above load was applied through weights attached to an epoxy sleeve fitted in the model as shown in the figure 5.

The following step depicts the Stress Freezing Procedure.

- The Centralizing spring model to be stress freezed is fixed in the fixture.
- The whole assembly of the model and fixture is loaded inside the stress-freezing oven.
- The estimated stress freezed load is applied through weights attached to an epoxy sleeve fitted in the model.
- The model is heated at the temperature of 70-degree with the load.
- Then model is soaked for about 1 to 2 hrs until a uniform temp., is obtained.
- The model is then cooled to the room temperature slowly for more than 10-12hrs.
- The component or model is coated with a layer of oil to improve transparency

Figure 5 Stress freezing arrangement with fixture and applied load

B Analysis of Stress frozen model (Centralizing Spring)

The stress-frozen model was analyzed for different flex webs as shown in the fig 6

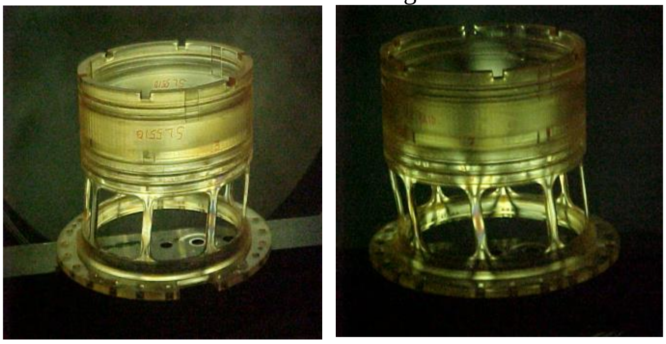

Figure 6 Stress Frozen Model Viewed in a Polariscope

The isochromatic fringe pattern for different flex webs is shown in figure 7

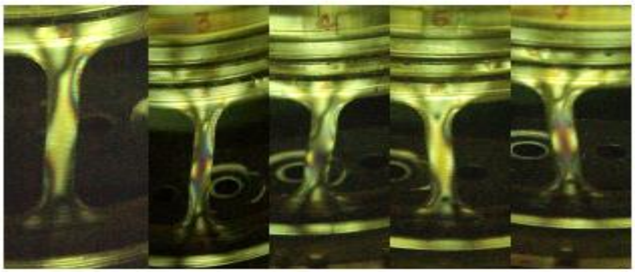

Figure 7 Iso-chromatic Fringe Pattern in Stress Frozen Flex Web

The table 1 shows the maximum fringe order at critical point is presented in terms of fringe order per unit thickness

Table 1: Fringe Order in Different Flex Webs

FLEX-WEB LOCATION	N (Fringe/mm)
Top	1.2
1-Left	1.35
Mid-Left	1.44
2-Left	1.56
Bottom	1.23
2-Right	1.5
Mid-Right	1.43
1-Right	1.34

Table 1: Fringe Order in Different Flex Webs

The Mid-Right and the Mid-Left flex webs show similar stress distribution as expected apriori. Since principal stress separation is to be done for each flex web, the isoclinic fringe patters was found for 0^0 , 15^0 , 30^0 , 45^0 , 60^0 , 75^0 & 90^0. The comparative isoclinic fringe patterns are shown in figure 9.

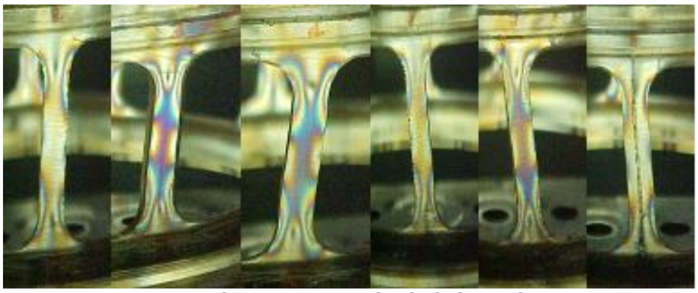

Fig. 9 Isoclinic Pattern in Individual Flex Webs

C. Results

Sample calculations are presented to determine the maximum principal stress data from the fringe order. The corresponding stress in the prototype made of SL5530 can be found by multiplying the photoelastic stress values by a load factor, (Load on the prototype/ Load on the model). In this case since the model is made to full scale, the scale factor is unity.

Maximum fringe order in Mid-Right flex web = 3.52

Slice thickness = 3mm , Stress optic coefficient = 0.257 Mpa/fringe/mm.

Principal stress difference ($\sigma_1 - \sigma_2$) = NF/t

At a free boundary = 0 so σ_1 = 0.3015 Mpa = 0.03074 Kgf/mm^2.

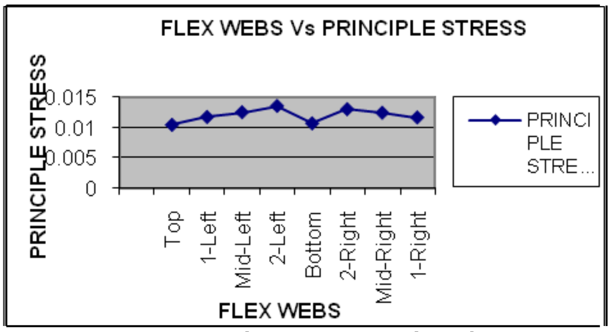

Fig 10: Principle Stresses Verses Flex webs

V Modeling with FEM and its Analysis

The centralizing spring cad model was imported from the cad domain with required material as shown in the figure 11a and Deformed mesh model in figure 11b.

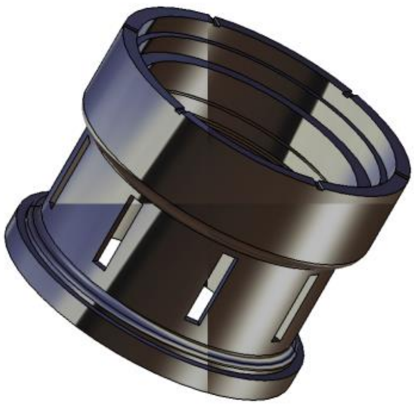

Fig 11 : FEM Model of centralizing spring for the ANSYS

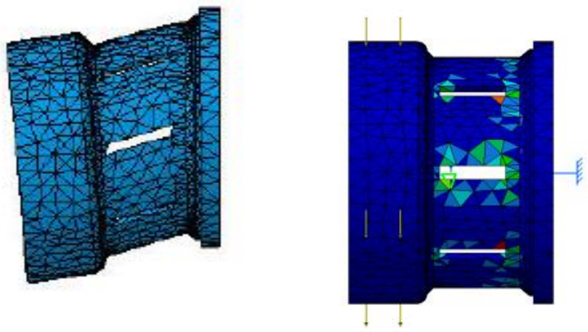

Fig 11b : Deformed mesh model

Fig 12: Boundary conditions

The boundary conditions with the specific material properties were considered to perform the analysis of the spring and the model is as shown in the fig 12. The stress distribution was found near the web due to the loading condition and hence an optimization of web is essential as shown in fig 13.

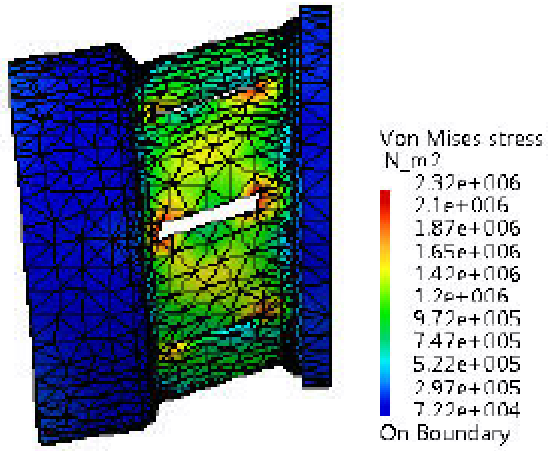

Fig 13: Von-mises stress in centralizing spring.

VI CONCLUSIONS

Remarkable reduction (in excess of 50%) in model preparation time is realized. Full-Scale 3D photoelastic model of a critical gas turbine engine component is made through stereolithography and through stress freezing technique, experimental analysis is performed & the Max., principle stress from the maximum fringe order is **0.3015Mpa** (or) **0.03074 Kgf/mm^2.**

The maximum stress value determined by finite element analysis due to axial loading and thrust produced in the component with photoelastic experimental stress analysis, this validates the FEM results. As the stress determined are validated, it represents the critical region of stress distribution are at web of the spring region. The optimized wed radius and its properties plays an important role for stress reduction will surely improve the fatigue life of the component.

In three–dimensional analysis, convergence can be expected to be more difficult to achieve because of additional computational costs of refinement in three dimensions, this report presents a basic understanding for three dimensional analyses and estimating the stress imparted to component. This improves the fatigue life and provides useful input and innovative technique to guide the industrial research program.

REFERENCES

[1] Raju, B.S., Chandrashekar, U., Drakashyani, D., (2013) “ Studies on application of rapid prototyping for the generation of photoelastic models and experimental analysis” , International Journal of application or innovation in Engineering and management, Vol 2, issue 2, 2013, page No:209 – 217.

[2] Allwin Yesuvadian. R., L.J.Sudev., B.S.Raju., (2011) “Stress analysis in dovetail attachment of compressor blade & disc using finite element analysis & photoelasticity” , International conference on Recent trends in Mechanical engineering, DETC2012-70056.

[3] Loebig, Thomas G. S., Anderson, Donald D. – “ Rapid prototyping modeling for three dimensional photoelastic stress analysis”, American society of Mechanical Engineer, Bioengineering Division, Volume 35, Page No: 389-390,1997.

[4] Calvert, Geoff – “Rapid prototyping for experimental analysis”. *IEE Colloquium (Digest),* No: 077, Mar 23 , Page No: 7/1 – 7/6, 1994.

[5] Hon & Onuh - “Application of Taguchi method and new hatch style for quality improvement in stereolithography”. *Proceedings of Institute of Mechanical Engineering*, Part B, Volume 212, Page NO: 461- 472.

[6] Folkestad; James, E., Johnson, Russell.L - “Integrated rapid prototyping and rapid tooling (IRPRT)”, Integrated Manufacturing Systems, Volume 13, N-2, 2002, Page No: 97-103, 2002.

[7] Xu,F. , Young.Y.S., Loh.H.T., “ Toward Generic Models for Comparative Evaluation and Process Selection in Rapid Prototyping Machines”, Journal of Manufacturing System , Volume 19 , No 5, pp 283 – 295,2000.

[8] Pham,D.T & Dimov.S.S., -“ Rapid Manufacturing” , 1st edition, Springer-Verlag London, 2001.

[9] Hon & Onuh- “Application of Taguchi method and new hatch style for quality improvement in stereolithography”. Proceedings of Institute of Mechanical Engineering, Part B, Volume 212, Page NO: 461- 472.

[10] User Manual – Introduction to Stereolithography” – *3D Systems*, 1980.

[11] Holister G.S. – “*Experimental Stress analysis*”, Cambridge, University Press, 1967.